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(19) (CA) **CANADIAN PATENT** (12)

(54) PROCESS AND APPARATUS FOP RAPID PYROLYSIS OF CARBONACEOUS MATERIALS

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BE IT KNOWN THAT CHARLES K. CHOI of 2366 North San Benito Court, Claremont, California 91711, United States of America, having made an invention entitled:

"Process and Apparatus for Rapid Pyrolysis of Carbonaceous Material"

the following disclosure contains a correct and full description of the invention and of the best mode known to the inventor of taking advantage of the same

ABSTRACT

Carbonaceous materials are rapidly pyrolyzed by feed of the carbonaceous material tangentially to a cyclone reaction-separation zone while introducing a stream of a particulate source of heat into the cyclone reaction-separation zone at an angle inclined to the path of travel of the carbonaceous material so that the streams exchange heat. The cyclone reaction-separation zone induces separation of solids consisting of the particulate carbon containing solid residue of pyrolysis and particulate heat source from a vapor stream which includes condensible and non-condensible hydrocarbon products of pyrolysis. The particulate source of heat and solid particulate carbon containing residue of pyrolysis are preferably transported to a cyclone burner and heated by partial combustion to a temperature suitable for feed to the cyclone reactor-separator. Rapid pyrolysis maximizes the yield of middle boiling hydrocarbons and olefins.

When the carbonaceous material is one likely to agglomerate or adhere to surfaces when being heated to pyrolysis temperature, for instance when the material is an agglomerative coal, a higher velocity stream of the particulate heat source may be introduced tangentially into the cyclone reaction-separation zone to form a layer between the injected carbonaceous material and the walls of cyclone reaction-separation zone.

The increasing scarcity of fluid fossil fuels, such as oil and natural gas is causing much attention to be directed towards converting solid carbonaceous materials such as coal, oil shale, and solid waste to liquid and gaseous hydrocarbons by pyrolyzing the solid carbonaceous material. Typically, pyrolysis occurs under non-oxidizing conditions in the presence of a particulate source of heat.

In the past, pyrolysis has been carried out in tubular reactors. While effective, the yield of middle boiling hydrocarbons, i.e. C_5 hydrocarbons to hydrocarbons having a boiling end point of about 950°F(510°C.) has been less than desired. Their loss has been attributed to protracted effective pyrolysis times which result in thermal cracking of such hydrocarbons. A need exists therefore for a more efficient pyrolysis process which maximizes the yield of the middle boiling hydrocarbons which are useful for the production of gasoline, diesel fuel, heating oil, and the like.

In one aspect the invention provides a process for the pyrolysis of carbonaceous materials wherein the carbonaceous material is primarily pyrolyzed by heat transferred thereto from a high temperature, particulate solid source of heat to yield as products of pyrolysis, a pyrolytic vapor including condensible and noncondensible hydrocarbons and a particulate carbon-containing solid residue, characterised by tangentially introducing to and passing along a curved path in a cyclone reaction-separation zone a stream of carbonaceous material, while introducing to said cyclone reaction-separation zone a

high temperature stream of the particulate solid source of heat, contained in a carrier gas which is non-deleteriously reactive with respect to the products of pyrolysis , at an angle inclined to the path of travel of carbonaceous material so as to penetrate and initiate pyrolysis of said carbonaceous material, the introduced quantity of particulate source of heat being sufficient to raise the carbonaceous material to a pyrolysis temperature of at least about 315°C, while simultaneously separating a gaseous mixture of the carrier gas and pyrolytic vapor from a solids mixture including the particulate solid source of heat and the carbon-containing solid residue by the action of centrifugal forces induced, at least in part by the introduction velociti s of each feed stream.

Preferably the introduction velocity of each said stream is from about 100 ft (30m) to about 250 ft (76m) per second so that the stream mix and rapidly exchange heat within a suitably short contact time. However, as will be explained, in certain embodiments of the invention it may be desirable to introduce the said streams at velocities nearer to the lower end of this velocity range while another stream of particulate solid heat source is introduced at a higher velocity for a purpose to be described.

The pyrolysis temperature is preferably within the range 315°C. to 1095°C. but desirably does not exceed about 760°C. while being at least about 480°C.

The operating parameters are preferably so selected that the pyrolysis occurs in a contact time

ranging from about 0.1 to about 3 seconds, more preferably in a contact time of not more than about 1 second.

Desirably the weight ratio of the particulate solid source of heat to carbonaceous material is from about 2 to about 10. Depending upon the selected value for this ratio and other operating parameters, the particulate solid source of heat may conveniently have a temperature ranging from 55 to about 280°C. above the pyrolysis temperature.

In preferred embodiments, the separated solids mixture obtained from the cyclone reaction-separation zone is passed to a cyclone combustion zone into which a stream of a gaseous source of oxygen is introduced, the solids mixture being introduced at an angle to this stream so as to heat the solids mixture, the heated solids mixture then being separated and recycled to the cyclone reaction-separation zone to serve as the particulate source of heat.

In preferred practice, the particulate solids mixture obtained from the cyclone reaction-separation zone is transferred to a first solids collection zone wherein the particles are maintained at least partly fluidized, being withdrawn from this collection zone and passed through a first fluidizing conduit to the said cyclone combustion zone., the heated particles obtained from this zone being fed to a second solids collection zone from which they are transported through a second, vertically oriented, fluidized conduit to the cyclone reaction-separation zone.

The separated gaseous mixture is preferably

withdrawn from the cyclone reaction-separation zone, the condensible hydrocarbons in that gaseous mixture being condensed and a light hydrocarbon fraction obtained from the condensate.

In this case, the process is advantageously further characterised by passing the said separated gaseous mixture to a venturi quench zone where by introduction of a quench fluid, the condensible hydrocarbons are condensed to yield a gaseous residue; passing the quench fluid, condensed hydrocarbons and gaseous residue to a fractional separation zone wherein the gaseous residue is separated from the condensed hydrocarbons and the condensed hydrocarbons are separated into a middle distillate light hydrocarbon fraction and a heavy hydrocarbon fraction; and recovering the light hydrocarbon fraction as product and recycling at least a portion of the heavy hydrocarbon fraction to the venturi quench zone as the said quench fluid.

When the process is to be applied to carbonaceous materials such as agglomerative coals that pass through a tacky state on being heated to the pyrolysis temperature and have a tendency, therefore, to agglomerate or adhere to any surfaces that they contact, such as a wall defining the cyclone reaction-separation zone, preferably an additional high temperature stream of particulate solid source of heat is introduced tangentially into the cyclone reaction-separation zone and caused to follow a curved path therein at a higher velocity than the said stream of carbonaceous material thereby to form a layer of source

of heat between said stream of carbonaceous material and a wall defining said zone.

In such embodiments of the invention, conveniently the said stream of carbonaceous material and the first said stream of particulate solid source of heat are introduced into the cyclone reaction-separation zone at velocities not greater than about 61 m per second, whereas said additional stream is introduced into said zone at a velocity in the range 61 to about 76 m per second.

The said additional stream may comprise from about 10 to about 50% by weight of the total amount of particulate solid source of heat introduced into said cyclone reaction-separation zone. However, preferably, said additional stream comprises 20 to 30% by weight of the total particulate solid source of heat introduced into said zone.

Especially when an additional stream of the particulate solid source of heat is introduced into the cyclone reaction-separation zone for the aforesaid purpose, the (first) said stream of the said source of heat is preferably introduced at an angle in the range 15 to 40° relative to the path of the stream of carbonaceous material. The most preferred values for such an angle are within the range 15 to 25°.

In another aspect, the invention also provides an apparatus for pyrolysis of a carbonaceous material in the presence of a particulate source of heat which comprises a high temperature cyclone separator-reactor having a tangential first feed inlet for a low velocity stream of carbonaceous material, and a second feed inlet for a low velocity stream of the particulate source of heat at an angle inclined to the tangential feed inlet, a vapor exhaust at one end of the cyclone separator-reactor for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon-containing solid products of pyrolysis.

The invention also provides apparatus for carrying out the process. Thus in another aspect the invention provides apparatus for pyrolysis of carbonaceous material in the presence of a particulate source of heat, characterised by a high temperature cyclone separator-

reactor having a tangential feed inlet for the carbonaceous material and a second feed inlet for the particulate source of heat at an angle inclined to the tangential feed inlet, a vapor exhaust at one end thereof for removal of vaporized products of pyrolysis and a solids outlet at tho opposed end thereof for removal of the particulate solid source of heat and carbon containing solid product of pyrolysis; quench means coupled in open receiving relation to said vapor exhaust outlet and including means for introduction of a hydrocarbon quench fluid for condensing at least a portion of the high temperature vapors received from the vapor exhaust outlet; means connected to the quench means for fractional separation of condensate from the quench means; means for receiving the particulate solid source of heat and carbon-containing solid products of pyrolysis, said means including means to at least partly to fluidize the collected particles; means to transport the particulate solid source of heat and carbon-containing solid product of pyrolysis to said combustion means; means to combust carbon contained in particulate solid source of heat and carbon-containing solid residue of pyrolysis; receiving means to receive the particulate solid source of heat from said cyclone burner; and means to transport particulate solid source of heat from said receiving means to the second feed inlet of said cyclone separator reactor.

The said means for fractional separation of the condensate from the quench means includes means to cycle a portion of a fractionally separated condensate

as quench fluid to said quench means.

In another aspect the invention provides an apparatus for pyrolysis of a carbonaceous material in the presence of a particulate source of heat, characterised by a high temperature cyclone separation-reactor having a first tangential feed inlet for a high velocity stream of the particulate source of heat, a second tangential feed inlet defining a flow path substantially parallel to the flow path defined by the first inlet for a low velocity stream of carbonaceous material, and a third feed inlet for a low velocity stream of the particulate source of heat at an angle inclined to the first and second feed inlets, a vapor exhaust at one end of the cyclone separation-reactor for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon containing solid products of pyrolysis.

Preferably, the third feed inlet is inclined at an angle from about 15 to about 40 degrees to the first and second inlets.

More preferably, the third feed inlet is inclined at an angle from about 15 to about 25 degrees to the first and second inlets.

Preferably the second and third feed inlets are adjacent.

The invention is further explained with reference to the accompanying drawings, in which:

Figure 1 illustrates apparatus suitable for carrying out the process of this invention;

Figure 2 is a diagrammatic top view of the cyclone reactor-separator of the apparatus of Figure 1;

Figure 3 is a diagrammatic top view of a cyclone burner;

Figure 4 is a diagrammatic elevation of a modified cyclone reactor-separator that may be utilised in certain embodiments of the invention;

Figure 5 is a sectional view on line 5-5 of Figure 4;

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and

FIGURE 6 is a sectional view on line 6 6 of Figure 4.

According to the present invention, there is provided a process for the pyrolysis of liquid and solid carbonaceous materials which may be used to maximize the yield of middle distillate hydrocarbons by extremely short pyrolysis contact times and apparatus therefore.

The carbonaceous materials which my be pyrolyzed in accordance with the present invention include solids such as agglomerative coals, nonagglomerative coals, tar sands, shale, oil shale, the organic portion of solid wastes and the like and liquids such as shale oils, tar sands oils, heavy refinery hydrocarbons and the heavy hydrocarbons which result from the pyrolysis operations as well as mixtures thereof. For solids, it is desirable to limit particle size to about 1000 microns, and to about 250 microns for the instance of agglomerative coals.

Referring first to Figures 1 and 2, carbonaceous material enters a feedline 10 along with, if necessary, a carrier gas 12 and, if desired steam, to a venturi mixer 14. If desired, the heavy hydrocarbon pyrolysis products may be combined with the feed and added by line 15. The carrier gas, if employed, is nondeleteriously reactive with respect to the products of pyrolysis. By the term "nondeleteriously reactive" as applied to the carrier gas or gas stream, there is meant a gas substantially free of free oxygen but which may contain

constituents which react with the pyrolysis products to upgrade their value. The gas should not, however, have constituents which by reaction degrade the pyrolysis products. The gas can serve as a diluent to minimize pyrolysis contact time and in the instance of solid carbonaceous materials it can serve as a transport gas. The carrier gas may, for instance, be the inert off-gas product of pyrolysis, steam which will react under suitable conditions with the char or coke formed from pyrolysis to yield hydrogen, by a water-gas shift reaction, which serves to react with and stabilize unsaturated products of pyrolysis, or any desired inert gas or mixtures thereof.

As best shown in Figure 2, the carbonaceous feed and the carrier gas, if present, are injected as a stream into a cyclone reactor-separator 16, tangentially to the walls thereof. Venturi mixer 14 serves to intimately mix the carbonaceous feed with the carrier gas to enhance dilution of the feed and so promote short reaction pyrolysis times.

Simultaneously, there is introduced a particulate solid source of heat, through a line 18, at an angle inclined to the path of travel of the stream of carbonaceous material. The solid particulate source of heat is transported into the pyrolysis reactor by a carrier gas which may be the same or different from the gas carrying the carbonaceous feed into the pyrolysis reactor, although it will be at a temperature approximately equal to the temperature of the particulate solid source of heat.

The hot particulate solids are supplied at a rate and at a temperature consonant with maintaining a temperature along the walls of the cyclone reactor separator 16 suitable for pyrolysis. Pyrolysis will initiate at about 600°F. (315°C.) but the pyrolysis temperature may range up to the softening temperature of the inorganic constituents of the particulate source of heat or the carbonaceous feed, higher temperatures leading to slagging or fusion. Preferably the pyrolysis temperature ranges from 600 to about 2000°F. (1095°C.). More typically, however, pyrolysis is conducted at a temperature from about 600 to about 1400°F. (760°C.) and preferably in the range 900 to about 1400°F. (480-760°C.) to maximize the yield of middle boiling hydrocarbons and olefins. Higher temperatures may be employed with equal ease to facilitate, where desired, gasification reactions.

Depending upon pyrolysis temperature, normally from about 2 to about 20 parts by weight of particulate solid source of heat are fed per part of carbonaceous material entering the reactor 16. The solids employed may be solids from a source external to the process, such as sand, or may be the solid product resulting from pyrolysis of the carbonaceous material such as char or coke or, in the instance of municipal solid waste, the glass-like inorganic residue resulting from the decarbonization of the solid residue of pyrolysis. The particulate source of heat is generally at a temperature from about 100 to about 500°F. (55-280°C.) above the desired pyrolysis temperature.

The streams of particulate solid source of heat, and of carbonaceous material, respectively, preferably both have a velocity within the range 100 to 250 feet (30-76m) per second.

The amount of gas employed to transport the solid carbonaceous material and the particulate source of heat is sufficient to maintain transport of the materials and avoid plugging and normally in excess of that amount to dilute materials and minimize pyrolysis contact time. Normally, the solids content will range from about 0.1 to about 10% by volume based on the total volume of the stream.

The particulate solid source of heat penetrates and enters the stream of carbonaceous material. This penetration initiates the rate of heat transfer from the particulate solid source of heat to the carbonaceous material, instantaneously causing pyrolysis which is a combination of vaporization and cracking reactions. As the vaporization and cracking reactions occur, condensible and non-condensible hydrocarbons are generated from the carbonaceous material with an attendant production of a carbon containing solid residue such as coke or char. The carbon containing solid residue and the particulate source of heat being the heaviest materials present are retained and pass spirally along the walls of the cyclone reactor separator 16 and settle to reservoir 17 at the base thereof. The carrier gas as well as the pyrolytic vapors separate in spiral vortex flow towards the centre of the cyclone reactor separator 16 and rapidly

terminate the primary pyrolysis reactions due to the absence of solids. Effective pyrolysis contact time will be less than 3 seconds, preferably from about 0.1 to 1 second, more preferably from 0.2 to about 0.6 second.

"Pyrolysis contact time" or "contact time" as referenced to pyrolysis, as used herein, means the time from when the carbonaceous material first contacts the particulate source of heat until the vaporized products separate from the particulate source of heat. A convenient measure of contact time is the average residence time of the carrier gas in the cyclone reactor-separator. The lower limit is that required to heat the carbonaceous material to the desired pyrolysis temperature. This is a function of particle size and concentration of solid particulate source of heat. For example, under average feed conditions, contact time to achieve about 1000°F.(540°C.) is about 1.5 seconds for particles of about 250 microns in diameter and 0.5 seconds for particles of 75 microns in diameter.

The carrier gas along with the pyrolytic vapor exit reactor 16 and enter a venturi mixer 20 where they are contacted with a quench fluid to reduce gas temperature at least below pyrolysis and cracking temperatures to prevent further cracking reactions from occurring. Preferably, the quench fluid reduces temperatures below the dew point of the condensible hydrocarbons. Typically a portion of the condensed heavier hydrocarbons formed from the pyrolysis reactor

is employed as a quench fluid and fed to the venturi mixer 20 by line 24. Immiscible quench oils may also be used and when used are separated from the products and recycled to venturi mixer 20.

The quench effluent, normally a mixture of gas and liquids, is fed to a fractionating tower 22. In the fractionating tower 22, the carrier gas and lighter hydrocarbons are separated from the middle distillate hydrocarbons which are, in turn, separated from heavy hydrocarbons. Normally, the gaseous cut, containing about C_4 hydrocarbons and less, exit the top of the fractionating tower 22 by line 26. The cut of about C_5 to hydrocarbons having an end boiling point of about 950°F. (510°C.) which constitutes gasoline, diesel and heating fuel components, is separated as middle distillate hydrocarbon products in line 28. A portion may be cooled and recycled as reflux.

The heavy hydrocarbon residue exits the base of fractionator 22 and is cooled. One portion is recycled as reflux, another as quench and the balance, if not recovered, as a product returned to cyclone reactor separator 16 to be pyrolyzed to extinction.

Because of short residence time and at pyrolysis temperatures below about 1400°F. (760°C.) the amount of C_4 hydrocarbons plus the carbon-containing solid residue of pyrolysis will be a minimum while the C_5 to 950°F. (510°C.) boiling end point fraction will be maximized. The C_4 and lower hydrocarbons will tend to be rich in olefins if hydrogen is not added to or generated in the cylone reactor-separator 16. The amount of C_4 or less hydrocarbons

generated will increase with pyrolysis temperature and pyrolysis contact time.

The presence of hydrogen during pyrolysis, whether internally generated or externally supplied, is desired to enhance stabilization of the hydrocarbons formed, particularly the heavier hydrocarbon to prevent their polymerization to tars.

The particulate carbon-containing solid residue of pyrolysis and the particulate solid source of heat exit the reservoir 17 and pass by a line 30 and collected in a fluidized stripper 32. A flow of a carrier gas which is also non-deleteriously reactive with respect to the products of pyrolysis enters the base of stripper 32 to maintain the solids in a mixed condition and in at least a semi-fluidized state. A flap 34 on the leg 30 prevents backflow of the gas into the cyclone. Rather, the gas is bypassed around cyclone reactor-separator 16 through a conduit 36 for combination with the feed. The gas serves to remove any of the hydrocarbon oils which result from pyrolysis from the surface of the particles and return them to the system for further pyrolysis.

The cooled particulate source of heat and the carbon-containing solid residue of pyrolysis are passed through a slide valve 38 and transported along an angle riser 40 and a vertical riser 42 to a combustion zone, preferably a cyclone burner 44, the cross section of which is depicted in Figure 3. The cyclone burner may be operated in conjunction with an identical cyclone burner 46 or simply a cyclone separator for fines. If

other combustion apparatus are used, a cyclone separator is employed to separate flue gases from the particulate source of heat.

Combustion cyclone 44 operates in a manner substantially identical to cyclone reactor-separator 16. The transport gas used to carry the particles to cyclone burner 44 may be air or flue gas, with the balance of the combustion air injected tangentially through a line 48. As shown in Figure 3, the solids penetrate the air stream at an angle and rapidly undergo oxidative combustion. The heavier particles rapidly pass through the air stream, so that effective combustion residence time is short, ranging from about 0.1 to about 0.6 second. As a consequence, even despite the fact that excess air is supplied, the effective residence time for combustion is short. As a result the amount of carbon dioxide generated will be maximized, as the faster carbon dioxide reaction rate is favoured as compared to the slower carbon monoxide reaction rate. As a consequence, the amount of heat generated per unit of carbon consumed is maximized. In general, partial combustion will yield a flue gas having a CO_2 to CO ratio of about 2 to 1.

The gases and fine solids which elude recovery from cyclone 44 enter cyclone 46 where additional air may be added, the cyclone 46 also preferably having the form depicted in Figure 3 for short contact time combustion. Alternatively, a simple cyclone separator may be employed. The high temperature particulate source of heat collected in cyclones 44 and 46 passes by standpipes 48 and 50 to a surge hopper 52. Surge hopper

52 is maintained at a temperature consonant with the operating temperature of the pyrolysis reactor 16 and generally from about 300 to about 500°F. (165-280°C) above the pyrolysi temperature.

As required, the particulate source of heat is passed through a standpipe 54, slide valve 56, angle riser 58 to the vertical riser 18 for feed to cyclone reactor-separator 16. Excess particles are withdrawn from surge hopper 52 through a screen siphon tube 60 as product char.

A gas which may be steam that becomes superheated by contact with the contained particulate source of heat and forms hydrogen by a water gas shift reaction, enters the surge hopper 52 and passes through a pass line 62 for feed to the cyclone 44 and cyclone 46 as part of the carrier gas. The use of the gas, however, is contingent on complete consumption of oxygen in cyclone 44 and 46 as the gas entering pyrolysis cyclone reactor-separator 16 must be substantially free of oxygen.

The transfer gas in the vertical riser 18 serves to accelerate the particulate source of heat to the velocity required for feed to cyclone reactor separator 16.

As has been mentioned, certain carbonaceous materials, especially agglomerative coals, pass through a tacky state upon being heated to pyrolysis temperatures so that particles thereof at temperatures within a certain range tend to adhere to and build up on any surfaces with which such particles may come into contact. Such a surface is the curved wall of a cyclone reactor-

separator such as shown at 16 in Figures 1 and 2. Although a system such as described with reference to Figures 1 to 3 can accomplish satisfactory pyrolysis of agglomerative coals, the system is preferably modified to incorporate a cyclone reactor-separator of the construction illustrated in Figures 4 to 6 when such coals constitute the feed so as to ensure avoidance of the problems involved in the pyrolysis of such coals.

Thus, Figures 4 to 6 illustrate a cyclone reactor-separator 110 consisting of a vertically oriented cylindrical body 112 merging into a conical section 114 below and axially aligned with the main body 112. Below the conical section there is a reservoir 116, which feeds a dipleg 118 serving as a solids outlet. A vapor exhaust conduit 120, which preferably is coaxial with the main body, extends from the bottom 122 out through the top 124 of the cylindrical main body section.

There are three side-by-side inlets 126, 128 and 130 communicating with the top portion of the main body section. The first feed inlet 126 is tangential to the cyclone reactor-separator wall 117 and is intended for a relatively high velocity stream of a particulate source of heat, whereas the adjacent second feed inlet 128, also tangential to the cyclone reactor-separator wall is intended for a lower velocity stream of carbonaceous material. The second feed inlet 128 defines a flow path parallel to the flow path defined by the first inlet 126. The third feed inlet 130 is intended for a relatively low velocity stream o. the

particulate source of heat. This inlet is inclined at an angle so as to direct this stream toward the streams entering through the first and second tangential feed inlets.

In the operation of this cyclone reactor-separator, a particulate solid source of heat is injected as a stream 132 into the cyclone reaction-separation zone tangentially to the walls thereof through the first inlet 126. The velocity of the stream 132 is preferably greater than about 200 feet (61m) per second so that the hot particles have sufficient momentum to travel along the inner wall of the cyclone reactor-separator along the path marked by the arrows 133 in Figure 5. The velocity of this stream preferably is less than about 250 feet (76m) per second so that the particles do not erode the inner wall 136 of the cyclone reactor-separator.

Simultaneously with the introduction of the relatively high velocity stream, there is introduced a lower velocity stream 134 containing the carbonaceous material, and if necessary a carrier gas. The carrier gas, if employed, is non-deleteriously reactive with respect to the products of pyrolysis, and serves as a diluent to minimize pyrolysis contact time and to dilute the carbonaceous material to prevent self-agglomeration.

The carbonaceous material is introduced so as to follow a path substantially parallel to the path followed by the high velocity stream 132 of the particulate source of heat when it is introduced into the cyclone. The velocity of the carbonaceous material stream is less than

the velocity of the stream 132 preferably being less than about 200 feet (61m) per second. This ensures that the carbonaceous material is separated from the inner surface of the wall 136 by a layer of the higher velocity stream of the particulate source of heat. Thus, the higher velocity stream has greater momentum and thereby preferentially travels along the inner wall 136 of the cyclone reactor-separator. The carbonaceous material preferably has a velocity of at least 100 feet (30m) per second so that sufficient centrifugal forces are induced in the particles in this stream to effect a separation of the gaseous products of pyrolysis and the carrier gas from the solid products of pyrolysis and the particulate source of heat.

The carbonaceous material travels along the flow path 138 marked by "+" signs 39 shown in Figure 5. This path is closer to the central vertical axis than of the flow path 133 of the higher velocity stream 132 of the particulate source of heat.

The carbonaceous material may be treated before it is fed to the cyclone reaction separation zone by processes such as removal of inorganic fractions by magnetic separation and classification, particularly in the case of municipal solid waste. The carbonaceous material also can be dried to reduce its moisture content. The solid carbonaceous material usually is comminuted to increase the surface area available for the pyrolysis reaction.

Simultaneously with the introduction of the carbonaceous material and the higher velocity stream of

the particulate source of heat, a lower velocity stream 140 of the high temperature particulate source of heat is introduced into the cyclone reactor-separator 110 through the third inlet 130 which is adjacent to the inlet 128 for the carbonaceous material and inclined at an angle to the path of travel 138 of the carbonaceous material.

Both the lower velocity and the higher velocity streams of the particulate source of heat may be transported into the pyrolysis reactor by a carrier gas nondeleteriously reactive with respect to pyrolysis product. The gas may be the same as or different from the gas carrying the carbonaceous feed into the pyrolysis reactor, although this carrier gas would preferably be at a temperature approximately equal to the temperature of the particulate solid source of heat.

Because the lower velocity particulate solid source of heat enters the pyrolysis reactor 110 at an angle inclined to the path 138 of travel of the carbonaceous material, it penetrates the path of the carbonaceous material, as shown by dotted line 142 in Figure 5. This penetration initiates heat transfer from the particulate solid source of heat to the carbonaceous material, causing pyrolysis which is a combination of vaporization and cracking reactions. As the vaporization and cracking reactions occur, condensible and noncondensible hydrocarbons are generated from the carbonaceous material with an attendant production of a carbon-containing solid residue such as coke or char. The carbon-containing solid residue and the particulate source of heat being the

heaviest materials present are retained and pass spirally along the walls of the cylindrical main body 112 and cone section 114 of the cyclone reactor-separator 110, pass through the reservoir 116, and are discharged through the dipleg outlet 118. The carrier gas as well as the pyrolytic vapors separate in spiral vortex flow towards the centre of the cyclone reactor-separator 110 as shown by line 119 in Figure 5, and rapidly terminate the primary pyrolysis reactions due to the absence of solids.

The lower velocity stream of the particulate source of heat preferably has a velocity approximately the same as that of the carbonaceous material, i.e. from about 100 to about 200 feet (30-61m) per second. If its velocity is greater than about 200 feet (61m) per second, the lower velocity particulate source of heat tends to carry a portion of the carbonaceous material up against the walls of the cyclone reactor-separator, and this may lead to caking. At velocities less than about 100 feet (30m) per second, there may be insufficient momentum to effect a good separation of vapors from solids in the cyclone reactor-separator.

Although the streams of carbonaceous material 134 and the particulate source of heat 140 introduced through the second inlet 128 and third inlet 130 respectively, have been described as "low velocity", what is meant is that their velocity is low as compared to the higher velocity stream 132 of the particulate source of heat introduced through the first inlet 126. The preferred minimum speed for streams 134 and 140 is

about 100 feet (30m) per second.

The distribution of the particulate source of heat between the high and low velocity streams 132 and 140 is a balance between two competing considerations. First, if less than about 10% of the particulate source of heat is used in the higher velocity stream, an inadequate layer of hot nonagglomerative particles is formed along the reactor inner wall 136 and thus carbonaceous material can agglomerate along the walls. Therefore it is preferred that at least 10% of the particulate source of heat be contained in the higher velocity stream 132.

The second consideration is the necessity of providing a sufficient amount of the particulate source of heat in the lower velocity stream 132 to raise the temperature of the carbonaceous material to the desired pyrolysis temperature. Only a limited amount of heat is transferred from the higher velocity stream to the carbonaceous material, and this is primarily due to heat transfer by convection and radiation. Therefore, preferably at least 50% of the particulate source of heat is included in the lower velocity stream, and more preferably from about 70 to about 80%, that is, the higher velocity stream 132 amounts to 20-30% of the total particulate solid source of heat introduced into the cyclone reactor-separator.

The solids mixture 148 discharged from the bottom outlet 118 of the cyclone reactor-separator 110 contains particulate solid source of heat and the carbon-containing solids residue. The solids residue may be used as the particulate source of heat by at least

partially oxidizing it in the presence of a source of oxygen such as air and recycling it back to the pyrolysis reactor 110, using for instance an arrangement as described in connection with Figure 1.

The gas stream 150 exiting the top outlet 112 from the pyrolysis reactor 110 contains pyrolytic vapors comprising hydrocarbons, carrier gases, and undesirable components such as hydrogen sulfide which may be generated in the pyrolysis reaction. The volatilized hydrocarbons produced by pyrolysis consist of condensible hydrocarbons which may be recovered by simply contacting the volatilized hydrocarbons with condensation means, and noncondensible hydrocarbons such as methane and other hydrocarbon gases which are not recoverable by ordinary condensation means. Condensible volatilized hydrocarbons can be separated and recovered by suitable recovery means for instance as described in connection with Figure 1. The undesirable gaseous products can be removed from the uncondensible hydrocarbons by conventional means such as chemical scrubbing. Remaining uncondensed hydrocarbons can be sold as a product gas stream and can be utilized as the carrier gas for carrying the carbonaceous material and the particulate source of heat to the pyrolysis reaction-separation zone.

Although the higher velocity stream 132 of the particulate source of heat has been described as being introduced tangentially into the cyclone reactor-separator, this stream may be inclined at a small angle relative to the wall of the cyclone. However, if the higher

velocity stream 132 is inclined toward the cyclone walls, increased erosion of these walls results, whereas if it is introduced inclined away from the cyclone walls, it tends to do a poorer job of keep carbonaceous material away from the walls of the cyclone. Similarly, the stream 134 of carbonaceous material does not have to be introduced strictly parallel to stream 132. However, it is undesirable to introduce the carbonaceous material in a path inclined towards the walls of the cyclone since this increases the chance of carbonaceous material caking on the wall. On the other hand, if the carbonaceous material is inclined towards the centre of the cyclone, this results in greater penetration of the carbonaceous material by the lower velocity stream of the particulate source of heat with potentially better heat transfer between these two streams, at the expense of increased pyrolysis time by reducing the effectiveness of solids/gases separation.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVELEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A process for the pyrolysis of carbonaceous materials wherein the carbonaceous material is primarily pyrolyzed by heat transferred thereto from a high temperature, particulate solid source of heat to yield, as products of pyrolysis, a pyrolytic vapor including condensible and noncondensible hydrocarbons and a particulate carbon-containing solid residue, comprising:

(a) tangentially introducing to and passing along the path formed by the curved inner surface of a cyclone reaction-separation zone having a vapor outlet at one end and a solids outlet at the base thereof, a stream of carbonaceous material, while;

(b) introducing to said cyclone reaction separation zone a high temperature stream of the particulate solid source of heat contained in a carrier gas which is non-deleteriously reactive with respect to the products of pyrolysis at an angle inclined to the path of travel of carbonaceous material to penetrate and initiate pyrolysis of said carbonaceous material, the introduced quantity of particulate source of heat being sufficient to raise the carbonaceous material to a pyrolysis temperature of at least about 600°F. while simultaneously;

(c) separating a gaseous mixture of the carrier gas and pyrolytic vapor from a solids mixture including the particulate solid source of heat and the carbon containing solids residue by the formation of flow patterns of each of the action of centrifugal forces induced, at least in part by the introduction velocities of each feed stream.

2. The process of claim 1 in which the introduction velocity of each stream is from about 100 to about 250 feet per second.

3. The process of claim 1 in which the pyrolysis temperature is from about 600 to about 2000°F.

4. The process of claim 1 in which the pyrolysis temperature is from about 600 to about 1400°F.

5. The process of claim 1 in which the pyrolysis temperature is from about 900 to about 1400°F.

6. The process of claim 1 in which pyrolysis is carried out in a contact time of from about 0.1 to about 3 seconds.

7. The process of claim 1 in which pyrolysis is carried out in a contact time of from about 0.1 to about 1 second.

8. The process of claim 1 in which the weight ratio of particulate solid source of heat to carbonaceous material is from about 2 to about 20.

9. The process of claim 1 in which the particulate source of heat is introduced at a temperature from about 100 to about 500°F. above the pyrolysis temperature.

10. The process of claim 1 in combination with the steps of:

(a) passing solids mixture to a cyclone combustion zone in which a stream of a gaseous source of oxygen is tangentially introduced to the cyclone combustion zone and the solids mixture at an angle inclined thereto to heat the solids to a temperature for introduction to the cyclone reaction separation zone; and

(b) separating the heated solid mixture from the cyclone combustion zone at the high velocity, high temperature particulate source of heat to the cyclone reactor separator.

11. A process of the pyrolysis of carbonaceous materials which comprises:

(a) tangentially introducing to and passing along the path formed by the curved inner surface of a cyclone reaction-separation zone having a vapor outlet at one end and a solids outlet at the opposed base thereof, a stream of carbonaceous material while:

(i) introducing to said cyclone reaction separation zone a high temperature stream of a particulate solid source of heat contained in a carrier gas which is non-deleteriously reactive with respect to products of pyrolysis at an angle inclined to the path of travel of said stream of carbonaceous material to penetrate and initiate pyrolysis of said carbonaceous material, the quantity of particulate source of heat introduced being sufficient to raise the carbonaceous material to a pyrolysis temperature of at least about 600°F. to yield a pyrolytic vapor comprised of condensible and normally noncondensible hydrocarbons and a particulate carbon-containing solid residue while simultaneously;

(ii) separating a gaseous mixture of the carrier gas and pyrolytic vapor from a particulate solids mixture of the particulate solid source of heat and the carbon-containing solid residue by the formation of separate flow patterns of each, the flow pattern created by

centrifugal forces induced at least in part by the high introduction velocities of each feed stream;

(b) withdrawing the gaseous mixture from the vapor outlet of the cyclone separation-reaction zone receiving the condensible hydrocarbons, and separating from the condensed hydrocarbons a light hydrocarbon fraction;

(c) withdrawing from the solids outlet of the cyclone reaction-separation zone the particulate solids mixture and transferring said particulate solid mixture to a first solids collection zone wherein the particles are maintained in a dense fluidized state;

(d) withdrawing from the first particles collection zone at least a portion of the particulate solids mixture and transporting the particulate solids mixture to a first inlet of a cyclone combustion zone, said first inlet being inclined to a second inlet through which a stream of a source of oxygen is tangentially introduced and rapidly combusting at least a portion of the carbon in the particulate solids mixture by impinging the particulate solids mixture into the flow of the source of oxygen entering zone to form the high temperature particulate solid source of heat and a flue gas; and

(e) removing the high temperature particulate solid source of heat from the cyclone combustion zone and tranporting the particulate solid source of heat to said cyclone reaction-separation zone.

12. A process as claimed in claim 11 in which the condenisble hydrocarbons are recovered by:

(a) passing the gaseous mixture to a venturi quench zone where by introduction of a quench fluid, the condensible hydrocarbons are condensed to yield a gaseous residue;

(b) passing the quench fluid, condensed hydrocarbons and gaseous residue to a fractional separation zone;

(c) separating in the fractional separation zone the gaseous residue from the condensed hydrocarbons and the condensed hydrocarbons into a middle distillate light hydrocarbon fraction and a heavy hydrocarbon fraction; and

(d) recovering the light hydrocarbon fraction as product and passing at least a portion of the heavy hydrocarbon fraction to the venturi quench zone as the quench fluid.

13. The process of claim 11 in which the introduction velocity of each stream is from about 100 to about 250 feet per second.

14. The process of claim 11 in which pyrolysis temperature is from about 600 to about 2000°F.

15. The process of claim 11 in which the pyrolysis temperature is from about 600 to about 1400°F.

16. The process of claim 11 in which the pyrolysis temperature is from about 900 to about 1400°F.

17. The process of claim 11 in which pyrolysis is carried out in a contact time of from about 0.1 to about 3 seconds.

18. The process of claim 11 in which pyrolysis is carried out in a contact time of about 0.1 to about 1 second.

19. The process of claim 11 in which the weight ratio of particulate solid source of heat to carbonaceous material is from about 2 to about 20.

20. The process of claim 11 in which the particulate source of heat is introduced at a temperature from about 100 to about 500°F. above the pyrolysis temperature.

21. A process for the pyrolysis of carbonaceous materials which comprises:

(a) tangentially introducing to and passing along the path formed by the curved inner surface of a cyclone reaction-separation zone having a vapor outlet at one end and a solids outlet at the opposed base thereof, a stream of carbonaceous material while:

(i) introducing to said cyclone reaction-separation zone a high temperature stream of a particulate solid source of heat contained in a carrier gas which is non-deleteriously reactive with respect to products of pyrolysis at an angle inclined to the path of travel of said stream of carbonaceous material to penetrate and initiate pyrolysis of said carbonaceous material, the quantity of particulate heat source of being sufficient to raise the carbonaceous material to a pyrolysis temperature of from about about 600° to about 1400°F within about 0.1 to about 3 seconds, to yield a pyrolytic vapor comprised of condensible and normally noncondensible hydrocarbons and a particulate carbon containing solid residue, while simultaneously;

(ii) separating a gaseous mixture of the carrier gas and pyrolytic vapor from a particulate solids mixture of the particulate solid source of heat and the carbon-containing solids residue by the formation of separate flow patterns of each, the flow

patterns created by centrifugal forces induced at least in part by the high introduction velocities of each feed stream;

(b) withdrawing the gaseous mixture from the vapor outlet of the cyclone separation-reaction zone and introducing the gaseous mixture to a quench zone where the hydrocarbons are condensed by contact with a quench fluid to have a gaseous residue;

(c) passing the effluent from the quench zone to a fractional separation zone wherein the gaseous residue is separated from the condensed hydrocarbons and the condensed hydrocarbons fractionated into a light hydrocarbon product and heavy hydrocarbons at least a portion of which is recovered as quench fluid;

(d) withdrawing from the solids outlet of the cyclone reaction-separation zone the particulate solids mixture and transferring the particulate solids mixture to a first solids collection zone wherein the particles are maintained in a dense fluidized state;

(e) withdrawing from the first particles collection zone at least a portion of the particulate solids mixture and passing the particulate solids mixture through a first fluidized conduit to a first inlet of a cyclone combustion zone, said first inlet being inclined to a second inlet through a stream of a gaseous source of oxygen tangentially introduced;

(f) rapidly combusting at least a portion of the solids mixture and particulate carbon in the cyclone burner by impinging the particulate solids mixture into the stream of the gaseous source of oxygen entering said cyclone combustion zone to form the high temperature particulate source of heat and a flue gas;

(g) removing the high temperature particulate solid source of heat cyclone from the combustion zone to a second particles collection zone; and

(h) withdrawing from the second particles collection zone a portion of the high temperature particulate solid source of heat to a second vertically oriented fluidized conduit and transporting said high temperature particulate solid source of heat to said cyclone reaction-separation zone.

22. The process of claim 21 in which the introduction velocity of each stream is from about 100 to about 250 feet per second.

23. The process of claim 21 in which the pyrolysis temperature is from about 900 to about 1400°F.

24. The process of claim 21 in which the contact time is from about 0.1 to about 1 second.

25. The process of claim 21 in which the weight ratio of particulate solid source of heat to carbonaceous material is from about 2 to about 20.

26. The process of claim 21 in which the particulate source of heat is introduced at a temperature from about 100 to about 500°F above the pyrolysis temperature.

27. Apparatus for pyrolysis of carbonaceous material in the presence of a particulate source of heat which comprises:

(a) a high temperature cyclone separator-reactor having a tangential first feed inlet for a low velocity stream of carbonaceous material, and a second feed inlet for a low velocity stream of the particulate source of heat at an angle inclined to the tangential feed inlet, a vapour exhaust at one end thereof for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon-containing solid product of pyrolysis;

(b) quench means coupled in open receiving relation to said vapor exhaust outlet and including means for introduction of a hydrocarbon quench fluid for condensing at least a portion of the high temperature vapors received from the vapor exhaust outlet;

(c) means connected to the quench means for fractional separation of condensate from the quench means;

(d) means for receiving the particulate solid source of heat and carbon-containing solid products of pyrolysis, said means including means to at least partly fluidize the collected particles;

(e) means to transport the particulate solid source of heat and carbon-containing solid product of pyrolysis to said combustion means;

(f) means to combust carbon contained in particulate solid source of heat and carbon-containing solid residue of pyrolysis;

(g) receiving means to receive the particulate solid source of heat from said cyclone burner; and

(h) means to transport particulate solid source of heat from said receiving means to the second feed inlet of said

cyclone separator-reactor.

28. Apparatus as claimed in claim 27 further comprising a tangential second feed inlet for a high velocity stream of the particulate source of heat defining a path substantially parallel to the flow path defined by the first feed inlet.

29. Apparatus as claimed in claim 27 or 28 in which means for fractional separation of the condensate from the quench means includes means to cycle a portion of a fractionally separated condensate as quench fluid to said quench means.

30. Apparatus for pyrolysis of carbonaceous material in the presence of a particulate source of heat which comprises:

(a) a high temperature cyclone separator-reactor having a tangential first feed inlet for the carbonaceous material and a second feed inlet for the particulate source of heat at an angle inclined to the tangential feed inlet, a vapor exhaust at one end thereof for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon-containing solid product of pyrolysis;

(b) quench means coupled in open receiving relation to said vapor exhaust outlet and including means for introduction of a hydrocarbon quench fluid for condensing at least a portion of the high temperature vapors received from the vapour exhaust outlet;

(c) means connected to the quench means for fractional separation of condensate from the quench means;

(d) means for receiving the particulate solid source of heat and carbon-containing solid products of pyrolysis, said means including means to at least partly fluidize the collected particles;

(e) first conduit means to transport the particulate solid source of heat and carbon-containing solid product of pyrolysis to the second inlet of the cyclone burner;

(f) at least one cyclone burner having a tangential inlet for a gaseous source of oxygen, a second inlet inclined at an angle to the tangential inlet for the gaseous source of oxygen for receiving transported particulate solid source of heat and carbon containing solid product of pyrolysis, a flue gas outlet at one end thereof and an outlet for formed particulate solid source of heat at the base thereof;

(g) receiving means to receive the particulate solid source of heat from said cyclone burner; and

(h) second conduit means to transport particulate solid source of heat from said receiving means to the second feed inlet of said cyclone separator-reactor.

31. Apparatus as claimed in claim 30 in which means for fractional separation of the condensate from the quench means includes means to cycle a portion of a fractionally separated condensate as quench fluid to said quench means.

32. A process for the pyrolysis of carbonaceous materials in which the carbonaceous material is primarily pyrolyzed by heat transferred thereto from a high temperature, particulate solid source of heat to yield, as products of pyrolysis, a pyrolytic vapor containing hydrocarbons and a particulate carbon-containing solid residue, comprising:

(a) tangentially introducing to and passing along a path formed by the curved inner surface of a cyclone reaction-separation zone having a vapor outlet at one end and a solids outlet at the base thereof, a high velocity, high temperature stream of the particulate source of heat, while;

(b) introducing to the cyclone reaction-separation zone a low, velocity stream of carbonaceous material in a flow path substantially parallel to the flow path of the high velocity stream of the particulate source of heat, wherein the high velocity stream of the particulate source of heat serves to prevent carbonaceous material contacting and agglomerating on the inner surface of the cyclone reaction-separation zone, while;

(c) introducing to the cyclone reaction-separation zone a low velocity, high temperature stream of the particulate solid source of heat at an angle inclined toward the path of travel of carbonaceous material to penetrate and initiate pyrolysis of the carbonaceous material, the introduced quantity of particulate source of heat in the low velocity and high velocity of streams being sufficient to raise the carbonaceous material to a pyrolysis temperature of at least about 600°F; and

(d) separating a gaseous stream containing the pyrolytic vapor from a solids mixture including the particulate solid source of heat and the carbon-containing solid residue by the formation of flow patterns of each by action of induced centrifugal forces.

33. A process as claimed in claim 32 in which the pyrolysis time is less than about 3 seconds.

34. A process as claimed in claim 32, in which the pyrolysis time is less than about 1 second.

35. A process of claim 32 in which the pyrolysis temperature is from 900 to about 1400°F.

36. The process of claim 32 in which the weight ratio of the particulate solid source of heat to carbonaceous material is from about 2 to about 20.

37. The process of claim 36 in which from about 10 to about 50% by weight of the particulate source of heat is in the high velocity stream.

38. The process of claim 36 in which from about 20 to about 30% by weight of particulate source of heat is in the high velocity stream.

39. The process of claim 32 in which from about 10 to about 50% by weight of the particulate source of heat is in the high velocity stream.

40. A process as claimed in claim 32 in which from about 20 to about 30% by weight of the particulate source of heat is in the high velocity stream.

41. The process of claim 32 in which the introduction velocity of the high velocity stream of the particulate source of heat is greater than about 200 feet per second and up to about 250 feet per second.

42. A process as claimed in claim 32 in which the introduction velocity of the carbonaceous material is from about 100 to about 200 feet per second.

43. The process of claim 32 in which the introduction velocity of the low velocity stream of particulate source of heat is from about 100 to about 200 feet per second.

44. The process of claim 32 in which the low velocity, high temperature stream of the particulate solid source of heat is introduced at an angle of from about 15 to about 40 degrees relative to the path of travel of the carbonaceous material.

45. The process of claim 32 in which the low velocity, high

temperature stream of the particulate solid source of heat is introduced at an angle of from about 15 to about 25 degrees relative to the path of travel of the carbonaceous material.

46. A process for the pyrolysis of coal, comprising:

(a) tangentially introducing to and passing along the path formed by the surface of a cyclone reaction-separation zone having a vapor outlet at one end and a solids outlet at the base thereof, a high velocity, high temperature stream of a particulate solid source of high containing char, while;

(b) introducing into the cyclone reaction-separation zone a stream of coal in a flow path substantially parallel to the path of travel of the high velocity stream of the particulate source of heat, wherein the high velocity stream of the particulate source of heat serves to prevent coal from contacting and agglomerating on the inner surface of the cyclone reaction-separation zone, while simultaneously;

(c) introducing to the cyclone reaction-separation zone a low velocity, high temperature stream of a particulate solid source of heat containing char, wherein the low velocity stream of the particulate solid source of heat is introduced inclined at an angle of from about 15 to about 40 degrees toward the path of travel of the coal to penetrate and initiate pyrolysis of the coal to yield as products of pyrolysis in a pyrolysis time of less than about 3 seconds, char and a pyrolytic vapor containing hydrocarbons, wherein the quantity of the particulate source of heat is sufficient to yield a weight ratio of the particulate source of heat contained in both the high and low velocity streams to the coal of from about 2 to about 8, and where from about 50 to about 90% of the particulate source of heat introduced to the cyclone reaction-separation zone is contained in the low velocity stream, and wherein the temperature of the particulate source of heat is

sufficient to raise the coal to a pyrolysis temperature of at least about 600°F; and

(d) separating a gas stream containing pyrolytic vapor from a solids mixture including the particulate solid source of heat and the char formed by the pyrolysis of the coal by the formation of flow patterns of each by action of induced centrifugal forces.

47. The process of claim 46 in which the introduction velocity of the high velocity stream of the particulate source of heat is greater than about 200 feet per second and up to about 250 feet per second.

48. A process as claimed in claim 46 in which the introduction velocity of the coal is from about 100 to about 200 feet per second.

49. The process of claim 46 in which the introduction velocity of the low velocity stream of particulate solid source of heat is from about 100 to about 200 feet per second.

50. A process as claimed in claim 46 in which the residue time of the carbonaceous material in the cyclone reaction-separation zone is from about 0.01 to about 0.5 seconds.

51. A process for the pyrolysis of a carbonaceous material, comprising:

(a) tangentially introducing to and passing along the path formed by the surface of a cyclone reaction-separation zone having a vpaor outlet at one end and a solids outlet at the base thereof a high velocity, a high temperature stream of a particulate solid source of heat, wherein the stream has an introduction velocity greater than about 200 feet per second and up to about 250 feet per second;

(b) introducing into the cyclone reaction-separation zone a stream of carbonaceous material having a velocity of from about 100 to about 200 feet per second adjacent to and in a flow path substantially parallel to the introduction path of travel of the high velocity stream of the particulate source of heat, wherein the high velocity stream of the particulate source of heat prevents the carbonaceous material from contacting the inner surface of the cyclone reaction-separation zone;

(c) introducing to the cyclone reaction-separation zone a low velocity, high temperature stream of a particulate solid source of heat and having a velocity of from about 100 to about 200 feet per second, wherein the low velocity stream of the particulate source of heat is introduced inclined at an angle of from about 15 to about 25 degrees toward the path of travel of the carbonaceous material to penetrate and initiate pyrolysis of the carbonaceous material to yield, as products of pyrolysis within a pyrolysis time of less than about 3 seconds, a carbon-containing solid residue and a pyrolytic vapor containing hydrocarbons, wherein the quantity of the particulate source of heat is sufficient to yield a weight ratio of the particulate source of heat contained in both the high and low velocity streams to the carbonaceous material of from about 2 to about 20 and where from about 70 to about 80% of the particulate source of heat introduced to the cyclone reaction-separation zone is contained in the low velocity stream, and wherein the temperature of the particulate source of heat is sufficient to raise the carbonaceous material to a pyrolysis temperature of from about 900°F to about 1400°F, while simultaneously;

(d) separating a gas stream containing pyrolytic vapors from a solids mixture including the particulate solid source of heat and the carbon containing solid residue formed by the pyrolysis of the carbonaceous material by the formation of flow

patterns of each by the action of centrifugal forces induced.

52. An apparatus for pyrolysis of a carbonaceous material in the presence of a particulate source of heat which comprises a high temperature cyclone separator-reactor having a tangential first feed inlet for a low velocity stream of carbonaceous material, and a second feed inlet for a low velocity stream of the particulate source of heat at an angle inclined to the tangential feed inlets, a vapor exhaust at one end of the cyclone separator-reactor for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon-containing solid products of pyrolysis.

53. An apparatus for pyrolysis of a carbonaceous material in the presence of a particulate source of heat which comprises a high temperature cyclone separator-reactor having a tangential first feed inlet for a low velocity stream of carbonaceous material, and a second feed inlet for a low velocity stream of the particulate source of heat at an angle inclined to the tangential feed inlets, and a tangential third feed inlet for a high velocity stream of the particulate source of heat defining a flow path substantially parallel to the flow path defined by the first inlet, a vapor exhaust at one end of the cyclone separator-reactor for removal of vaporized products of pyrolysis and a solids outlet at the opposed end thereof for removal of the particulate solid source of heat and carbon-containing solid products of pyrolysis.

54. An apparatus as claimed in claim 52 in which the second feed inlet is inclined at an angle of from about 15 to about 40 degrees to the first and second inlets.

55. An apparatus as claimed in claim 52 in which the second feed inlet is inclined at an angle from about 15 to about 25 degrees to the first and third inlets.

56. An apparatus as claimed in claim 51 in which the first and thiru feed inlets are adjacent.

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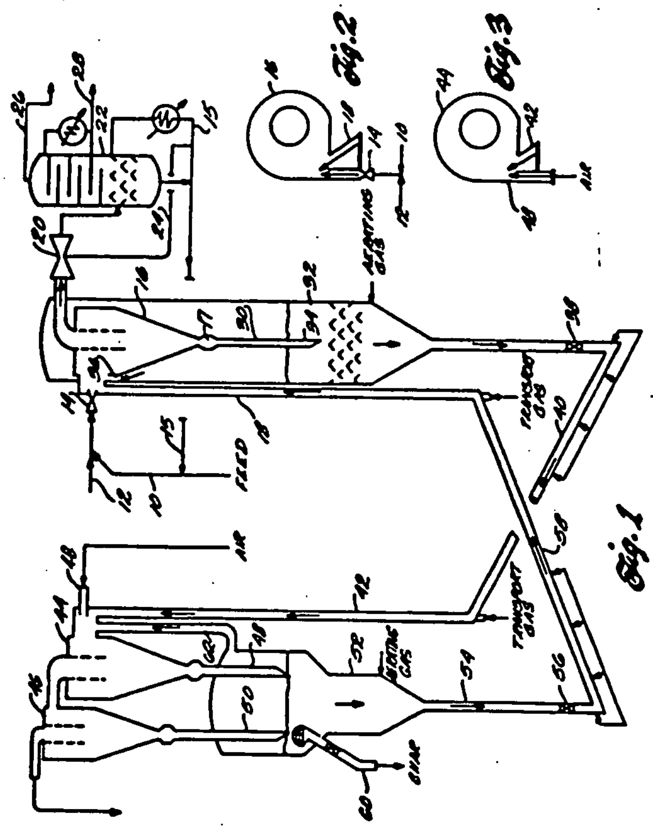

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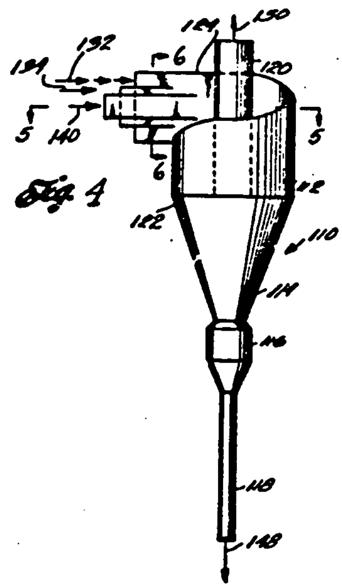


Fig. 4

Fig. 5

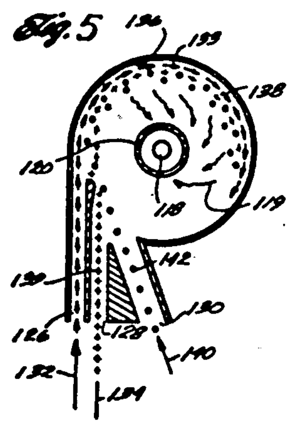
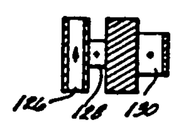


Fig. 6



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